BELLCOMM, INC.

SUBJECT: Simulation of Saturn V Launch to Earth Orbit with a Hohmann Transfer and S-IVB Circularization
Case 610

DATE: October 16, 1967

FROM: P. H. Whipple

ABSTRACT

It is anticipated that some Apollo Applications missions may be flown at altitudes sufficiently high that an ascent trajectory containing a Hohmann transfer orbit will be more efficient than a direct ascent. The Bellcomm Apollo Simulation Program (BCMASP) has been modified to simulate the Saturn V launch and ascent to a circular earth orbit, using a direct injection into a Hohmann transfer ellipse as part of the ascent trajectory. A two burn S-IVB is assumed for injection into the transfer orbit and for circularization at the apogee of the transfer orbit.

The modified BCMASP program can be used in either of two modes. In the payload optimization mode, the program will automatically do successive simulations of the trajectory from launch to circular orbit insertion until the maximum delivered payload is determined. In the reference trajectory mode, the payload and mission are specified and the program generates a reference trajectory for this mission. The user has the option of a propulsive or non-propulsive S-IVB vent during the Hohmann transfer coast.

Practical extensions of the program include its usage with the Uprated Saturn I launch vehicle, the incorporation of a three-burn S-IVB capability with an earth orbit coast prior to transfer orbit insertion, and the addition of plane change capability during the S-IVB burns.

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MEMORANDUM FOR FILE

I. INTRODUCTION

The Apollo Applications Program will include earth orbital missions at low and high altitudes. Some of these missions may be at altitudes that are too high to efficiently reach with a direct ascent to circular orbit and will therefore use a Hohmann transfer as part of the ascent trajectory. To aid in mission analysis work for these missions, the Bellcomm Apollo Simulation Program (BCMASP) has been modified to simulate the launch and ascent to orbit for this type of ascent scheme.

II. PROGRAM DESCRIPTION

A. General Description

The launch trajectory consists of a Saturn V launch and direct injection into the transfer orbit, using the S-IC, S-II and the first burn of the S-IVB stage. The vehicle then coasts to apogee where the circularization is achieved with the second burn of the S-IVB stage.

If the circularization is achieved in the simulation without consuming all of the available S-IVB propellant, the payload weight is increased and the trajectory is simulated again. This process is repeated until all of the available S-IVB propellant is consumed and the maximum payload weight is obtained. If a reference trajectory for a mission with a specified payload is desired, then this iteration option can be inhibited and only one trajectory simulation is run.

Other options that would normally be exercised are (1) the optimizing of total vehicle weight into the transfer orbit, and (2) the optimizing of total weight into the desired circular orbit. The former is accomplished as in a nominal LOR mission, i.e., by varying the kick angle during the S-IC burn, the initial pitch angle for the S-II burn, and the pitch rate during the S-II burn to find the combination of these parameters yielding the maximum weight delivered into the transfer orbit. The latter optimization is accomplished by varying the ignition time of the second S-IVB burn and the pitch angle during this burn. In addition, the option to use a propulsive or non-propulsive vent for the S-IVB during the Hohmann transfer coast is available.

At the completion of the payload optimization process, the program automatically computes estimates of deorbit propellant for various specified weights of the CSM, assuming a retrograde service module deorbit burn into an elliptic trajectory with a user-specified perigee.

This program has been used to study the Saturn V payload capability for circular earth orbits with altitudes varying from about 19,000 nautical miles to 30,000 nautical miles. The results of this study will be reported at a later date.

B. Subroutine Description

The sequence of events for the ascent trajectory is provided to the program by the events list, or subroutine SIMTGT. The subroutine TRJSEL provides the basic instructions for proceeding through a trajectory simulation by calling the appropriate subroutines in the correct sequence and implementing the payload optimization option. These subroutines were in large part rewritten for this modification to the BCMASP. Lesser changes were made to the subroutines SVTB and ETHORB, and the new subroutines PUNT1 and SYNORB were based largely on the BCMASP subroutines HUNTI and ETHORB. Each of these is described briefly below.

SIMTGT (Events List)

A listing of subroutine SIMTGT without equivalence, common, or dimension statements is given in Appendix I. During the S-IC and S-II phases of powered flight, the sequence of events is essentially the same as in a nominal LOR mission. At the cutoff of the S-II stage the altitude is very close to the user-specified perigee altitude of the transfer orbit. The S-IVB develops sufficient velocity to pass through the circularization condition at perigee and continues to burn until an elliptic transfer orbit with an apogee altitude equal to the desired final circular orbit altitude is achieved. The CONIC subroutine is used to predict the apogee radius and determine the S-IVB cutoff time to achieve this elliptic orbit. Since this apogee prediction is based on a conic trajectory and the simulated trajectory during the ensuing coast period is an integrated trajectory, the apogee altitude attained will be slightly different than expected. To compensate for this, a slight bias may be included in the user-specified circular orbit altitude. Immediately after the first S-IVB cutoff, an initial estimate of the second S-IVB ignition time is computed.

After the direct injection into the transfer orbit, the space vehicle begins a coast period that extends almost until apogee is reached. The user must specify if the propulsive or non-propulsive S-IVB venting scheme is to be used.

The second ignition of the S-IVB stage for the circularization burn is represented as EVENT S4ON2 and has as its criterion the ignition time, TON2. If the user so specifies, the circularization burn is repeated with values for the ignition time and pitch angle other than the initial estimates. In this way, the combination of these two quantities that yields the maximum payload at circularization burn cut-off is found. To enable the program to vary the ignition time, EVENT S4ON2 is preceded by the physically fictitious EVENT PREON2 whose criterion is a computed time that is not varied.

At the events S4OFF1, S4ON2, and S4OFF2, the user may subtract specified weights from the current vehicle weight. This is a convenient way to discard thrust buildup and decay propellants, as well as other items that may conveniently be considered to be jettisoned instantaneously at these times.

The last event in the events list, EVENT STOP, is used as a convenient place to compute estimates of deorbit propellant. This computation is applicable to a retrograde service module burn which inserts the deorbiting CSM into an elliptic orbit with a perigee altitude specified by the user. This computation is done for CSM weights that vary from 20,000 lbs. to 60,000 lbs. after the deorbit burn, in increments of 10,000 lbs. The targeting mode printout for each case consists of the weight of the CSM before and after the deorbit burn and the deorbit propellant.

TRJSEL

A listing of the TRJSEL without the equivalence and common statements is shown in Appendix II. The first operation performed by TRJSEL is the computation of various initialization conditions. This is a slight departure from the normal usage of the BCMASP and will be discussed in the next section. The subroutines that effect the trajectory simulation are then called in turn, commencing with ETHORB and concluding with SYNORB. When SYNORB returns control of the program to TRJSEL, the vehicle has been placed in a circular earth orbit. Subroutine TRJSEL tests for any leftover S-IVB propellant that was not needed to place the payload in orbit. If the value of this remaining S-IVB propellant is large and positive, then more payload could have been placed in orbit. If the value of this remaining S-IVB propellant is large and negative, then more S-IVB propellant was consumed in the simulation than is actually available and the orbited payload is unrealistically high. In either case, if the program is run in the payload optimization mode, the payload weight is adjusted by adding an amount equal to this leftover S-IVB propellant, multiplied by a convergence factor. After the total space vehicle weights at required times in the trajectory are correspondingly adjusted, the simulation is repeated with these adjusted weights.

When a simulation run is completed and the leftover S-IVB propellant is acceptably small, i.e., practically all of the S-IVB propellant was consumed, a final simulation run is made without the optimization subroutines but using the optimum parameter values determined previously. This final run will generate the data for the processing that will follow after the completion of the targeting run. The targeting run is completed by outputing the total weight placed in orbit, the weight of the S-IVB stage and IU, and the launch vehicle payload weight above the IU.

The program output at the end of the targeting run produced by the SIMTGT and TRJSEL subroutines is shown in Fig. 1 for an example run. From this information the discretionary payload weight is almost immediately available. By specifying a deorbited CSM weight, the deorbit propellant and CSM weight prior to the deorbit burn are immediately available. By subtracting the latter number from the launch vehicle payload in orbit, the available payload that can be carried to orbit and left or discarded in orbit is obtained. Conversely, the weight of experimental equipment and data that can be returned in the command module with the crew can be easily determined.

ETHORB, SVTB

Very minor modifications were made in these subroutines. Subroutine ETHORB performs the same function as in a nominal LOR mission. ETHORB varies the pitch parameters during the S-IC and S-II powered flight phases to determine the combination of those parameters delivering the maximum vehicle weight at the circular parking orbit condition and into the transfer orbit. Subroutine SVTB was modified to extend the range of the propulsive vent table and to add data for the non-propulsive vent option.

SYNORB, PUNT1

Subroutine SYNORB is based largely on ETHORB and is used at the final circularization burn. Subroutine SYNORB provides the logic for varying the pitch angle and ignition time in the optimization procedure discussed above under subroutine SIMTGT. Subroutine PUNT1 is called by SYNORB to optimize the vehicle weight at cutoff by varying the pitch angle. Subroutine PUNT1 is based largely on subroutine HUNT1 of the BCMASP.

C. Input and Output

Input

The required input data consists of launch vehicle data, targeting variables, and trajectory parameters.

Many of the launch vehicle items required as input for the BCMASP when used for an LOR simulation are also required with this modification. These include the following:

- Thrust levels and weight rates for each stage and mixture ratio used.
- Available propellants for the S-IC and S-II stages.
- Weight of the S-IC/S-II interstage.
- Weight of the Launch Escape System.
- Various times such as time of S-IC kick, coast time between S-IC shutdown and S-II ignition, time of S-II mixture ratio changes, etc.

As used for an LOR mission, the total space vehicle weight at S-IC liftoff (WGT 1), S-II ignition (WGT 2A), and S-IVB first ignition (WGT 3) are required. As used with this modification, the BCMASP requires three other input weights, (WLV 1, WLV 2A, WLV 3) in lieu of WGT 1, WGT 2A, and WGT 3. These are weights of the launch vehicle only at S-IC liftoff, S-II ignition, and S-IVB first ignition. With an initial estimate of the payload, PLEST, subroutine TRJSEL computes WGT 1, WGT 2A, and WGT 3 as part of its initial computations. After the input quantities WLV 1, WLV 2A, WLV 3, and PLEST have been chosen for an initial trajectory simulation, subsequent simulations for different missions may be run by changing only the payload estimate, PLEST, rather than all of these input weight values.

The input data for the targeting variables consist of the specification of program options, tolerances on the variables used in the optimization routines, and the convergence factor used in subroutine TRJSEL.

The input data for the trajectory parameters include the following:

- Initial estimates of the quantities to be varied in the optimization subroutines (S-IC kick angle, etc.)
- The transfer orbit perigee altitude in nautical miles.
- The desired circular orbit altitude in nautical miles.
- The deorbit ellipse perigee altitude in feet.
- Launch azimuth.
- Other specified values (e.g., flight path angle at circularization burn cutoff).

The modifications to the program provide for accepting the altitude variables mentioned above in the most easily specified manner and converting them to corresponding radii, measured in feet, for usage by the main program.

Output

The program output for the targeting run consists mainly of printout indicating the progress of the optimization subroutines, and the printout shown in Figure 1 and discussed earlier. In addition, projected perigee altitudes are printed out at several times during the circularization burn, assuming instantaneous thrust termination. This is helpful in estimating flight propellant reserve requirements, particularly for high altitude missions where an orbit achieved due to an early thrust termination may be acceptable, though slightly different from the intended orbit.

The program output format for the process run has not been changed from the standard BCMASP format for an LOR mission. An example of one page of the process mode output is shown in Figure 2.

III. FURTHER EXTENSIONS OF THE BCMASP

The BCMASP as modified and discussed in this memorandum is intended primarily to serve two purposes: to determine the maximum payload capability of the Saturn V launch vehicle into a prescribed circular earth orbit, using a Hohmann transfer as part of the ascent trajectory; and to generate a reference trajectory for a mission with a specified payload and orbital altitude with this ascent scheme. Some additional extensions of this program modification include using the Uprated Saturn I launch vehicle in place of the Saturn V, incorporating a three-burn capability for the S-IVB stage by adding a low earth orbit coast period prior to transfer orbit injection, and the addition of plane change capability during the S-IVB burns to achieve orbital inclinations other than those attainable by varying the launch azimuth. It does not appear that any of these modifications would be difficult to implement.

IV. ACKNOWLEDGEMENTS

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P. H. Whipple

1021-PHW-dcs

Attachments
Appendix I
Appendix II
Figure 1
Figure 2

APPENDIX I

```
OPTION SIMTGT  LIST,REF,ERFILE
C
C
C      LAUNCH VERTICALLY FROM THE SURFACE OF THE EARTH.
C
 EVENT LAUNCH(START)
 CRITERION (T=0.)
       WGT=WGTI
       CALL ELINIT
       CALL SVTB(1)
C
C      INITIATE THE GRAVITY TURN.
C
 EVENT KICK(LAUNCH)
 CRITERION (T=TKICK)
       CALL IKICK
C
C         END GRAVITY TURN
C
 EVENT ENDGT(LAUNCH)
 CRITERION (T=140.)
       IGT=0
       OMEGAP=0.
       OMEGAY=0.
C
C      SHUTDOWN THE STAGE ONE CENTER ENGINE.
C
 EVENT S1ENG5(KICK,S1ENG5)
 CRITERION (T=TENG5)
       CALL SVTB(2)
       WS1OFF=WGT1-FUEL1
C
C      SHUTDOWN THE STAGE ONE ENGINES.
C
 EVENT S1OFF (KICK)
 CRITERION (WGT=WS1OFF)
       TSAV=T+TC2
       ITHR=0
       DWGT=0
C
C      START THE STAGE TWO ENGINES.
C
 EVENT S2ON (S1OFF)
 CRITERION (T=TSAV)
C
C
       WGT=WGT2A
       ITHR=1
       CALL SVTB(3)
       TSAV1=T+TMIX1
       TSAV2=T+TJTISG
       TSAV3=T+TJTLES
       TSAV4=T+TMIX2
       WS2OFF=WGT2A-FUEL2-WGTLES-WGTISG
C
```

```
C            FIRST S2 MIXTURE RATIO CHANGE
C
 EVENT MIX1 (S2ON,S2OFF)
 CRITERION (T=TSAV1)
       CALL SVTB(4)
C
C       JETTISON THE STAGE ONE/TWO INTERSTAGE SECTION.
C
 EVENT JETISG(S2ON,S2OFF)
 CRITERION (T=TSAV2)
       WGT=WGT-WGTISG
C
C       JETTISON THE LAUNCH ESCAPE SYSTEM.
C
 EVENT JETLES (S2ON,S2OFF)
 CRITERION (T=TSAV3)
       WGT=WGT-WGTLES
       IDRAG=0
       ILIFT=0
       OMEGAP=DTH2
       CALL IPITCH(DLTH2)
C
C
C            SECOND S2 MIXTURE RATIO CHANGE
C
 EVENT MIX2 (S2ON,S2OFF)
 CRITERION (T=TSAV4)
       CALL SVTB(5)
C
C       SHUTDOWN THE STAGE TWO ENGINES.
C
 EVENT S2OFF (S2ON)
 CRITERION (WGT=WS2OFF)
       TSAV=T+TC3
       DWGT=0
       ITHR=0
C
C       START THE STAGE THREE ENGINES (S4B ROCKET) FOR ITS
C       FIRST BURN
C
 EVENT S4ON1 (S2OFF)
 CRITERION (T=TSAV)
       WGT=WGT3
       CALL SVTB(6)
 AUXEQ
       V=VALUE(VX)
       VCIR=SQRT(GME/R)
C
C CIRCULARIZATION CONDITIONS ARE ACHIEVED, HOWEVER, THE S4B
C IS NOT CUT OFF UNTIL THE NEXT EVENT, AFTER PERIGEE INSERTION
C IS ACHIEVED
C
 EVENT CIRCON (S4ON1)
 CRITERION(V=VCIR)
       CALL SVTB(6)
```

```
      CALL RESETT
C
      ALTDFT=ALTDNM*FTMILE
      RAPOGR=ALTDFT+REGEOD
      IF(ISKPSW.NE.0)  GO TO 200
      WRITE(6,110) ALTDNM,ALTDFT,RAPOGR
 110  FORMAT(/10X,9H ALTDNM =,F12.4,2HNM,10X,9H ALTDFT =,F15.3,
     12HFT,10X,9H RAPOGR =,F15.3,2HFT/)
C
 200  CONTINUE
 AUXEQ
      BETAI=BETA(RX,VX)
      CALL CONIC(RX,VX,ICOORD,3,RAPOG,TEMP1,TEMP2,TAPOG)
      IF(ISKPSW.NE.0)  GO TO 201
      WRITE(6,101) RAPOG,TAPOG
 101  FORMAT(8H RAPOG =E15.8,5X,8H TAPOG =E15.8)
 201  CONTINUE
C
C
C SHUTDOWN THE S4B ENGINE, TRANSFER ORBIT ACHIEVED
C
 EVENT S4OFF1 (CIRCON)
 CRITERION(RAPOG=RAPOGR)
C
      WGT=WGT-WDROP1
      CALL SVTB(8)
      BETAI=BETA(RX,VX)
      CALL ORIENT(0.,0.)
      V=VALUE(VX)
C
      VCIRC=SQRT(GME/RAPOG)
      VAPOG=(R/RAPOG)*V*COS(BETAI*DTOR)
      DELTAV=VCIRC-VAPOG
      AXP=(DELTAV*DWGT)/(GSTD*THR3)
      CPROP=WGT*(1.0-EXP(-AXP))
      TOVER2=CPROP/(2.0*DWGT)
      TPREO2=TAPOG-2.0*TOVER2
      WRITE(6,103) VCIRC,VAPOG,DELTAV,AXP
      WRITE(6,105) CPROP,TOVER2,TPREO2
 103  FORMAT(9H0 VCIRC =,F10.3,3X,8H VAPOG =,F10.3,3X,9H DELTAV =,
     1F10.3,3X,6H AXP =,F10.6)
 105  FORMAT(9H0 CPROP =,F10.2,3X,9H TOVER2 =,F9.4,3X,9H TPREO2 =,F12.4)
 AUXEQ
C
C
 EVENT PREON2 (S4OFF1)
 CRITERION(T=TPREO2)
      CALL RESETT
      ITHR=0
      DWGT=0
C
C START THE S4B ENGINE FOR THE CIRCULARIZATION BURN
C
 EVENT S4ON2 (PREON2)
 CRITERION(T=TON2)
```

```
      WGT=WGT-WDROP2
      CALL ORIENT(PSI6,TH6)
      OMEGAP=DTH6
      CALL SVTR(7)
      WGTON2=WGT
C
 AUXEQ
      BETAI=BETA(RX,VX)
      V=VALUE(VX)
      VCIR=SQRT(GME/R)
C
      IF(ISKPSW.NE.0) GO TO 202
      CALL CONIC(RX,VX,ICOORD,1,RPERIG,TEMP1,TEMP2,TPERIG)
      TNOW=T-TON2
      TTHEN=(TPERIG-TON2)/3600.
      APERNM=(RPERIG-REGEOD)/FTMILE
      WGONE2=WGTON2-WGT
      WRITE(6,104) TNOW,APERNM,TTHEN,WGONE2
 104  FORMAT(/2X,4H T =,F8.3,1X,1HS,3X,10H PER ALT =,F10.3,1X,2HNM,
     13X,10HT TO PER =,F7.3,1X,3HHRS,3X,6HPROP =,F12.3)
 202  CONTINUE
C
C SHUTDOWN THE S4B ENGINE, CIRCULARIZATION VELOCITY IS
C ACHIEVED
C
 EVENT S4OFF2(S4ON2)
 CRITERION(V=VCIR)
      ITHR=0
      DWGT=0.
      WGT=WGT-WDROP3
      BETAI=BETA(RX,VX)
      BETOF2=BETAI
      VCIR2=V
      TBURN2=T-TON2
      WGTORB=WGT
      ALTNM=ALT/FTMILE
      WRITE(6,102) WGTORB,VCIR2,TBURN2,BETOF2,ALTNM
 102  FORMAT(/9H WGTORB =,F12.2,3X,8H VCIR2 =,F10.2,3X,9H TBURN2 =,
     1F8.3,3X,9H BETOF2 =,F9.4,3X,8H ALTNM =,F12.4)
      TSAVS=T+1.
 AUXEQ
C
C
 EVENT STOP(S4OFF2)
 CRITERION(T=TSAVS)
      WRITE(6,106) ENTRYH
      ENTRYR=ENTRYH+REGEOD
      ECCEN=(R-ENTRYR)/(R+ENTRYR)
      VAPRTN=SQRT((GME*(1.-ECCEN))/R)
      V=VALUE(VX)
      VRETRO=V-VAPRTN
      VPERTN=SQRT((GME*(1.+ECCEN))/ENTRYR)
      WRITE(6,107) VRETRO,VAPRTN, VPERTN
C
      WTCSMF=20000.
```

```
C
      K=1
 10   WTCSMI=WTCSMF*(EXP(VRETRO/(GSTD*311.5)))
      DEPROP=WTCSMI-WTCSMF
      WRITE(6,108) WTCSMF, DEPROP, WTCSMI
      K=K+1
      WTCSMF=WTCSMF+10000.
      IF(K.LE.5) GO TO 10
C
C
 106  FORMAT(//3X,46HA FIRST ORDER ESTIMATE OF THE REQUIRED DEORBIT/
     13X,46HPROPELLANT, ASSUMING A RETROGRADE SM BURN INTO/3X,
     235HAN ORBIT WITH A PERIGEE ALTITUDE OF,F9.0,1X,2HFT)
C
 107  FORMAT(/6X,9HRETRO V =,F9.2,1X,3HFPS,3X,7HAPO V =,F9.2,
     11X,3HFPS,3X,7HPER V =,F9.2,1X,3HFPS)
C
 108  FORMAT(9H WTCSMF =,F8.1,1X,3HLBS,5X,9H DEPROP =,F8.1,1X,3HLBS,
     15X,9H WTCSMI =,F8.1,1X,3HLBS)
C
 LAST
```

APPENDIX II

```
OPTION TRJSEL  LIST,REF,ERFILE
      SUBROUTINE TRJSEL
C
C
C  OPTIMIZE FOR WEIGHT THROUGH LOW ALTITUDE CIRCULARIZATION CONDITION
C
      N=0
      WGT1=PLEST+WLV1
      WGT2A=PLEST+WLV2A
      WGT3=PLEST+WLV3
      WSVDRY=SVQUIT+PLEST
      REO=PALTNM*FTMILE+REGEOD

 1    ISKPSW=1
      N=N+1
      CALL ETHORB
      CALL ROLLBK(6HCIRCON)
C
C  INTEGRATE THROUGH TRANSFER TRAJECTORY TO APOGEE
C
      CALL FLTINT(6HCIRCON,6HPREON2)
      CALL ROLLBK(6HPREON2)
      CALL SYNORB
C
C  TEST FOR PROPER PROPELLANT USAGE
C
      DELTAW=WGTORB-WSVDRY
      WRITE(6,100) N,WGTORB,DELTAW
C
      WRITE(6,101) Z,WGT1,WGT2A,WGT3,WSVDRY
      IF((ABS(DELTAW).LE.QWTORB).OR.(IWTOPT.NE.1).OR.(N.GE.4)) GO TO 9
C
C  COMPUTE IMPROVED WEIGHT VALUES
C
      WGT1=WGT1+Z*DELTAW
      WGT2A=WGT2A+Z*DELTAW
      WGT3=WGT3+Z*DELTAW
      WSVDRY=WSVDRY+Z*DELTAW
      CALL ROLLBK(6HLAUNCH)
      WRITE(6,40)
      WRITE(6,50)
      GO TO 1
C
C  COMPUTE FINAL TRAJECTORY WITH IMPROVED VALUES OF VARIABLES
C
 9    ISKPSW=0
      WRITE(6,50)
      CALL ROLLBK(6HLAUNCH)
      CALL FLTINT(6HLAUNCH,4HSTOP)
      WRITE(6,20) DLTH1,DLTH2,DTH2,TON2,TH6,DTH6
      WRITE(6,30)
      IF(IWTOPT.NE.1)  GO TO 11
      IF((ABS(DELTAW).GT.QWTORB).AND.(N.GE.4))  GO TO 8
C
C EXIT FOR OPTIMIZED ORBITED WEIGHT
```

```
C
      PAYLOD=WGTORB-SVQUIT
      WRITE(6,70) WGTORB,SVQUIT,PAYLOD
      RETURN
C
C  EXIT FOR PROPELLANT NON-CONVERGENCE
C
 8    WRITE(6,60)
      RETURN
C
C  EXIT FOR NON-OPTIMIZATION RUN
C
 11   WPROPX=FUEL3-DELTAW
      WRITE(6,25) FUEL3,WPROPX,DELTAW
      RETURN
C
 20   FORMAT(/9X,8H DLTH1 =,F15.9,3X,8H DLTH2 =,F15.9,3X,8H DTH2  =,
     1F15.9//9X,8H TON2  =,F9.4,9X,8H TH6   =,F15.9,3X,8H DTH6  =,F15.9)
C
C
 25   FORMAT(1H1,///27H AVAILABLE S4B PROPELLANT =,F11.2,6HPOUNDS//
     127H S4B PROPELLANT EXPENDED  =,F11.2,6HPOUNDS//
     227H S4B PROPELLANT REMAINING =,F11.2,6HPOUNDS)
C
C
 30   FORMAT(//9X,38HCIRCULAR ORBIT ACHIEVED, RUN COMPLETED)
C
C
 40   FORMAT(///9X,44HRERUN TRAJECTORY WITH IMPROVED WEIGHT VALUES)
C
C
 50   FORMAT(1H1)
C
C
 60   FORMAT(/9X,39HCONVERGENCE FOR PROPER PROPELLANT USAGE//
     19X,26HNOT ACHIEVED**RUN TERMINATED)
C
 70   FORMAT(1H1,///10X,33HTOTAL WEIGHT IN ORBIT IS         =,3X,
     1F8.0,1X,6HPOUNDS//10X,33HWEIGHT OF S4B AND IU IN ORBIT   =,
     23X,F8.0,1X,6HPOUNDS//10X,33HLAUNCH VEHICLE PAYLOAD IN ORBIT =,
     33X,F8.0,1X,6HPOUNDS)
C
C
 100  FORMAT(//4X,4H N =I3,8X,9H WGTORB =E15.8,5X,9H DELTAW =E15.8)
C
 101  FORMAT(//4X,4H Z =,F6.2,5X,9H WGT1   =E15.8,5X,9H WGT2A  =E15.8,
     15X,9H WGT3   =E15.8,5X,9H WSVDRY =E15.8)
      END
```

```
A FIRST ORDER ESTIMATE OF THE REQUIRED DEORBIT
PROPELLANT, ASSUMING A RETROGRADE SM BURN INTO
AN ORBIT WITH A PERIGEE ALTITUDE OF  400000. FT

    RETRO V =  4873.76 FPS   APO V =  5215.08 FPS   PER V = 33819.71 FPS
WTCSMF = 20000.0 LBS         DEPROP = 12525.6 LBS        WTCSMI = 32525.6 LBS
WTCSMF = 30000.0 LBS         DEPROP = 18788.4 LBS        WTCSMI = 48788.4 LBS
WTCSMF = 40000.0 LBS         DEPROP = 25051.3 LBS        WTCSMI = 65051.3 LBS
WTCSMF = 50000.0 LBS         DEPROP = 31314.1 LBS        WTCSMI = 81314.1 LBS
WTCSMF = 60000.0 LBS         DEPROP = 37576.9 LBS        WTCSMI = 97576.9 LBS


    CIRCULAR ORBIT ACHIEVED, RUN COMPLETED


      TOTAL WEIGHT IN ORBIT IS          =    112384. POUNDS

      WEIGHT OF S4B AND IU IN ORBIT     =     37687. POUNDS

      LAUNCH VEHICLE PAYLOAD IN ORBIT =       74697. POUNDS
```

FIGURE 1

563


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 6 DEC. 1967     5 HR  55 MIN  35.695 SEC            -0 DAY   5 HR  55 MIN  35.695 SEC                                20719.9998
GEOCENTRIC FREE FLIGHT
 DATE    2439830.50  TIME       21335.6946  ICOUNT          5075  HNORM     32.0000000  ALT       133371661.  WGT         158770.072
 RX      -128053036.  VX         927.545303  DVIX  4.9080310E-01  REMX  8.3858696E 08  RTMX -9.6663899E 08  DWGT  1.3816787E-01
 RY      -56244295.0  VY       -4597.55322  DVIY  2.1557889E-01  REMY -8.0517604E 08  RTMY  7.4893174E 08  THRUST  -0.
 RZ      -65142725.5  VZ         796.915726  DVIZ  2.4970056E-01  REMZ -4.6723270E 08  RTMZ  4.0208998E 08  OMEGAP-1.0391139E-01
 R     1.5428482E 08  V         4757.40582  DVI   5.9136476E-01  REM   1.2529351E 09  GINCL     28.5187693  OMEGAY    0.
 XLATC   -25.0864499  XLON        40.7217484  ALFAI     75.9768620  BETAI      6.8780317  ASNODE   -96.6395397  OMEGAR    0.

 6 DEC. 1967     6 HR  13 MIN  16.179 SEC            -0 DAY   6 HR  13 MIN  16.179 SEC                                21780.4844
GEOCENTRIC FREE FLIGHT
 DATE    2439830.50  TIME       22396.1792  ICOUNT          5109  HNORM     32.0000000  ALT       133724627.  WGT         158625.654
 RX      -126792059.  VX        1443.47285  DVIX  4.8265758E-01  REMX  8.6692120E 08  RTMX -9.9371326E 08  DWGT  1.3419520E-01
 RY      -60995638.0  VY       -4360.21344  DVIY  2.3219124E-01  REMY -7.8446605E 08  RTMY  7.2347041E 08  THRUST  -0.
 RZ      -64158287.5  VZ        1058.70192  DVIZ  2.4424503E-01  REMZ -4.5748712E 08  RTMZ  3.9332883E 08  OMEGAP-1.0391139E- 1
 R     1.5463822E 08  V         4713.37720  DVI   5.8866522E-01  REM   1.2554815E 09  GINCL     28.5188510  OMEGAY    0.
 XLATC   -24.6222694  XLON        38.2699203  ALFAI     75.1487551  BETAI      1.17989731  ASNODE   -96.6398373  OMEGAR    0.

•••• EVENT PREON2 AT TIME        0.      AFTER   1 STEPS

 6 DEC. 1967     6 HR  13 MIN  16.179 SEC            -0 DAY   6 HR  13 MIN  16.179 SEC                                    0.
GEOCENTRIC FREE FLIGHT
 DATE    2439830.50  TIME       22396.1792  ICOUNT          5109  HNORM     32.0000000  ALT       133724627.  WGT         158625.654
 RX      -126792059.  VX        1443.47285  DVIX  4.8265758E-01  REMX  8.6692120E 08  RTMX -9.9371326E 08  DWGT    0.
 RY      -60995638.0  VY       -4360.21344  DVIY  2.3219124E-01  REMY -7.8446605E 08  RTMY  7.2347041E 08  THRUST   0.
 RZ      -64158287.5  VZ        1058.70192  DVIZ  2.4424503E-01  REMZ -4.5748712E 08  RTMZ  3.9332883E 08  OMEGAP-1.0391139E-01
 R     1.5463822E 08  V         4713.37720  DVI   5.8866522E-01  REM   1.2554815E 09  GINCL     28.5188510  OMEGAY    0.
 XLATC   -24.6222694  XLON        38.2699203  ALFAI     75.1487551  BETAI      1.17989731  ASNODE   -96.6398373  OMEGAR    0.

 6 DEC. 1967     6 HR  13 MIN  59.955 SEC            -0 DAY   6 HR  13 MIN  59.955 SEC                                43.7759523
GEOCENTRIC FREE FLIGHT
 DATE    2439830.50  TIME       22439.9551  ICOUNT          5111  HNORM     32.0000000  ALT       133728431.  WGT         158625.654
 RX      -126728407.  VX        1464.59555  DVIX  4.8237953E-01  REMX  8.6692120E 08  RTMX -9.9364960E 08  DWGT    0.
 RY      -61186268.0  VY       -4359.03357  DVIY  2.3289973E-01  REMY -7.8446605E 08  RTMY  7.2327976E 08  THRUST   0.
 RZ      -64111777.5  VZ        1069.38969  DVIZ  2.4404961E-01  REMZ -4.5748712E 08  RTMZ  3.9337541E 08  OMEGAP-1.0391139E-01
 R     1.5464204E 08  V         4712.89196  DVI   5.8863614E-01  REM   1.2554815E 09  GINCL     28.5188541  OMEGAY    0.
 XLATC   -24.6025870  XLON        38.1682434  ALFAI     75.1150780  BETAI  9.4312191E-01  ASNODE   -96.6398506  OMEGAR    0.

•••• EVENT S4ON2  AT TIME      43.776 AFTER   1 STEPS

 6 DEC. 1967     6 HR  13 MIN  59.955 SEC            -0 DAY   6 HR  13 MIN  59.955 SEC                                43.7759523
GEOCENTRIC POWERED FLIGHT
 DATE    2439830.50  TIME       22439.9551  ICOUNT          5111  HNORM     32.0000000  ALT       133728431.  WGT         157892.654
 RX      -126728407.  VX        1464.59555  DVIX     16.4541605  VAX       2679.60260  RHOA  1.3100391E-08  DWGT        548.690269
 RY      -61186288.0  VY       -4359.03357  DVIY    -43.0802989  VAY       8133.53259  PRESSA 5.0779926E-05 THRUST      233347.000
 RZ      -64111777.5  VZ        1069.38969  DVIZ     11.6381006  VAZ        900.681389  THETA -8.1348515E-01 OMEGAP    0.
 R     1.5464204E 08  V         4712.89196  DVI      47.5615067  VA        8610.79834  GINCL     28.5188541  OMEGAY    0.
 XLATC   -24.6025870  XLON        38.1682434  ALFAI     75.1150780  BETAI  9.4312191E-01  DNODE     89.9033203  OMEGAR    0.
 FLIFT    0.          DRAG         0.         FMACH      9.74079169  BETAA    -42.2307491
 CD    1.6[illegible]E-01  CL          0.         QALPHA 4.6191145E-01  QAERO  3.3727070E-03  PRX   1.8848201E-37  VPX      -4147.27043
 FISP     425.2[illegible]  AXIALA     47.5495043  ALPHA     136.955700  APHIT     150.697355  RPY   1.2571895E 22  VPY   1.8848316E-37
 DAHI     0.          AHI   2.7516617E 08  DELTAV     0.                                   RPZ   1.8848201E-37  VPZ   1.8848201E-37
```

FIGURE 2

BELLCOMM, INC.

Subject: Simulation of Saturn V Launch to Earth Orbit with a Hohmann Transfer and S-IVB Circularization
Case 600-1

From: P. H. Whipple

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